# Evolution of Normal Galaxies: HST Morphologies and Deep Spectroscopy

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**Abstract.** I review progress in understanding the evolution of normal field and cluster galaxies through the combination of HST imaging and ground-based spectroscopy. These data suggest that the bulk of the star formation producing the present-day galaxy population occurred at accessible redshifts, $z$ <2. Furthermore, a surprising amount of the detailed processing that shaped the Hubble sequence and morphology-density relation occurred surprisingly recently. The stage is thus set for a concerted attack on these questions with the present generation of 8-10 metre large telescopes. An important step forward will be the development of efficient survey techniques for the systematic exploration of the $z$ >1 Universe. Some possible approaches are briefly discussed.

## 1 Introduction and the Role of Instrumentation

These are exciting times in the fields of observational cosmology, galaxy formation and evolution. The rate of publications on bulletin boards like SISSA is one (albeit possibly unreliable) indicator of interest. At the time of writing almost a third of all 1996 preprints thus far are in some way connected with these topics. One is also struck by the optimism in many minds that we are close to resolving one of the outstanding questions of modern cosmology, namely 'When did galaxies form?'. Lest we be over-optimistic about the progress we have apparently made, some of which I review below, it is salutory to recall Zel'dovich's enthusiastic remarks when he summarised the 1977 IAU Symposium on 'Large Scale Structure' in Tallinn. He claimed '..extrapolating to the next symposium in the early eighties, one can be pretty sure that the question of the formation of galaxies and clusters will be solved'!

Although it pays to be cautious in reviews, with results in abundance from the refurbished HST (not least from the remarkable Hubble Deep Field), and the first deep spectroscopic studies emerging from the Keck telescope, it is a timely moment to look ahead and discuss, in the context of the VLT, the respective roles of HST and large ground-based telescopes.

In planning programmes with the VLT, one must surely now take into account the quite remarkable capabilities of HST. HST already offers ≃1 kpc image resolution at all redshifts in most conventional cosmologies and to this will soon be added long-slit spectroscopy and infrared imaging provided STIS and NICMOS are delivered according to schedule.

HST is *not*, as one often sees quoted, a 'small aperture telescope'. At wavelengths where the ground-based sky is dominated by OH emission, HST offers a

significant gain. For background-limited work, HST has an aperture equivalent to a 6.5m ground-based instrument. Furthermore, the wavelength range where this advantage accrues ($0.8< \lambda < 1.6$ $\mu$m) is particularly crucial in studies of the $z$ >1 Universe. Likewise, although HST does suffer from having a small field of view, it is not yet clear whether large aperture telescopes using adaptive optics will recover resolution approaching that of HST over a big enough field to make an appreciable gain. And in the longer term, HST's Advanced Camera will offer an important step forward.

Therefore, I would contend that the traditional 'complementarity' between HST and ground-based telescopes has been overstated and that ground-based telescopes should, at least in this scientific area, respond with imaginative instrumentation. Their big advantage over HST is the ability, at least in principle, to respond rapidly to both technological progress and scientific developments. Rapid interplay is important in both directions. One example of science driving instrumentation might be the discovery that the remarkably small angular sizes of the majority of star forming sources in the Hubble Deep Field has significant implications for ground-based instruments designed to study them. An example of technology driving scientific capability is the recent availability of large format HgCdTe arrays which opens up the prospect of survey spectroscopy at high redshifts. Such interaction should ensure ground-based telescopes maintain a cutting edge in years to come.

Yet, with a few exceptions, much of the instrumentation being developed for the 8 metre telescopes coming online is of the 'monumental' variety. By this I mean large $3-5M general purpose instruments which have taken many years to develop and, because of the cost and associated wide community involvement, often become the brainchilds of committees preoccupied primarily with technical reliability and financial management. Although important considerations, I'm confident many would agree that we should ensure at least some funds are set aside for instrumentation that can be developed quickly to exploit what is, after all, a rapidly moving subject.

This article, therefore, addresses the progress made in understanding the evolution of normal galaxies from both HST and ground-based telescopes. §2 discusses the progress made in the study of cluster spheroidal galaxies together with the important implications these results may have on the visibility of distant primordial sources. I also make some remarks on the environmental effects occurring in clusters. §3 discusses results on the evolution of field galaxies, particularly in the context of the faint blue galaxy problem and deep imaging from HST. Finally, in §4 I speculate briefly on ways in which we might systematically explore the $z$ >1 Universe.

## 2 The Star Formation History of Cluster Galaxies

Ellipticals were traditionally imagined to be simple stellar systems whose stars were formed in a single burst of star formation at high redshift (Tinsley & Gunn 1976, Sandage & Visvanathan 1978, Bower et al 1992). The popularity of

this hypothesis is easy to understand. Such systems are convenient for theorists to model and, as their ancestors should be luminous primaeval galaxies, the hypothesis produce exciting opportunities for observers too!

However, in the past decade, the simple picture has been under concerted attack. Many local ellipticals show evidence for intermediate-age stellar populations (O'Connell 1980) and dynamical peculiarities seen in many (dust-lanes, shells etc) can be readily explained if they formed more recently via the merger of gas-rich systems (Toomre 1977, Quinn 1984). Such arguments suggest a continued formation of ellipticals to quite low redshifts.

The conflict might be resolved if some ellipticals were old single burst systems, whereas the remainder formed via merging of gas-rich disk galaxies. In this case one might expect an environmental and/or mass dependence in the rate of occurrence of intermediate age populations. Reasonably good evidence is emerging that recent star formation is more prevalent in low density environments than in clusters. Rose et al (1994) find the mean stellar dwarf/giant ratio is higher in environments with low virial temperatures. This would be consistent with other environmental trends which indicate accelerated star formation histories in clusters (Oemler 1991). Kauffmann et al (1996) have suggested deep field redshift surveys indicate a paucity of high $z$ red spheroidals, although the reliability with which such systems can be identified using ground-based colours needs to be verified with HST data.

The sensitivity of the $U$-band light to small numbers of hot, young stars enabled Bower et al (1992) to conclude that no more than 10% of the current stellar population in present-day E/S0s could have been formed in any subsequent activity in the past 5 Gyr as might be the case if merging of gas-rich systems had been involved. This result presents an important challenge for hierarchical theories of structure based on dark matter halos since these predict relatively recent formation eras for massive galaxies. Kauffman (1996) and Baugh et al (1996) have addressed the question quantitatively using a simple prescription for merger-induced star formation. They find that the homogeneity of Bower et al's colour-magnitude (c-m) data can be satisfied if the merging of disk galaxies that produce spheroidals was largely complete by a redshift $z \simeq 0.5$.

Although good progress has been made in tracking the UV-optical c-m relation to higher redshift (Ellis et al 1985, Aragón-Salamanca et al 1991, 1993), without morphological information a major uncertainty remains. The scatter of the photometric c-m relation may be underestimated if some spheroidal galaxies lie blueward of the c-m sequence. This could well be the case if the timescale for dynamical evolution is shorter than that for main sequence evolution as indicated in numerical simulations (Mihos 1995, Barger et al 1996a).

The MORPHS team (Dressler et al 1996) have recently extended the analysis of Bower et al to a sample of three $z \simeq 0.54$ clusters, taking advantage of HST to morphologically classify a sample of 177 faint spheroidal galaxies (Ellis et al 1996a). The clusters cover a range of optical richnesses and X-ray luminosities within a narrow redshift interval specifically chosen so that observed colours are close to rest-frame $U-V$. Overall, the morphological selection of Es appears

reliable to $I$=23. However, the distinction between E and S0 galaxies becomes somewhat uncertain fainter than $I$=21-22.

**Fig. 1.** Colour-magnitude diagram for morphologically-classified galaxies in 0016+16 ($z$=0.54) from the 'MORPHS' project (Ellis et al 1996a). Es are indicated by filled circles, S0's by triangles and E/S0s by squares. Those spheroidals and compact objects known to be field galaxies or discounted from the analysis are indicated by open circles.The small scatter in the rest-frame $U - V$ colours of the spheroidal population in this and other clusters argues that the bulk of the stars formed before a redshift 3.

The rest-frame $U-V$ colour-magnitude relations (Figure 1) for the morphologically-confirmed spheroidals in these clusters show remarkably small scatter (<0.1 mag rms) and there is no evidence the scatter for S0s is any larger than that for Es. After accounting for photometric errors, the intrinsic scatter is about 0.07 mag uniformly to $I$=23 ($M_V = -17.8 + 5$ log$h$). Moreover, the combined sample shows little evidence of cross-cluster differences at a level greater than the internal scatter. The most straightforward interpretation is that the bulk of the star formation in cluster spheroidals occurred at least 5 Gyr before a redshift of $z$=0.54, i.e. $z$ >3 unless $H_o$ is low or $\Lambda \neq$0.

Although this result is consistent with analyses of larger samples of distant clusters (Aragón-Salamanca et al 1993), it does not necessarily apply generally to *all* elliptical galaxies, even those in clusters. Franx & van Dokkum (1996) warn of selection effects that might operate if ellipticals are identified morphologically in ways that guarantee they are least 2-3 Gyr old at any redshift. The most robust statement that can be made is that the stars that form the dominant proportion of red light in 3 $z$=0.54 clusters most likely formed before $z \simeq$3. Thus there is every incentive to search for the star-forming ancestors of these galaxies.

Some of the above caveats might be minimised by examining the evolution of

spheroidal galaxies in terms of mass/light ratios rather than broad-band luminosities. Impressive progress has been made of late in measuring stellar velocity dispersions (Franx & van Dokkum 1996, Bender et al 1996) and HST scale sizes (Pahre et al 1996, Barger et al 1996b) for high redshift galaxies. Preliminary results indicate only modest evolutionary changes consistent with passive evolution from a burst of star formation at high $z$. However, the selection biases above will only ultimately be overcome with a comprehensive sample of field spheroidals studied in a variety of ways. That Kauffmann et al (1996) and Lilly et al (1995) should come to rather different conclusions from analyses of the same CFRS dataset on the rate of evolution of field ellipticals is an indication of the degree of uncertainty inherent in the presently-available small samples.

How does the above help us to understand the physical origin of the morphology-density relation (Dressler 1980) which, according to observational evidence, was produced at quite low redshifts by environmental effects (Butcher & Oemler 1978, Allington-Smith et al 1993)? Morphological surveys of distant clusters such as those discussed above (Couch et al 1994, Dressler et al 1994) delineate a clear change in the morphological mixture in the sense that the proportion of disk galaxies was much greater in the past, apparently at the expense of a declining S0 population.

One traditional explanation for this evolution, viz. the transformation of spirals to S0s, goes a long way towards explaining the HST results (Dressler et al 1996). The cluster ellipticals provide a backbone of stability over a large range in redshift. By contrast, gas-rich spirals enter the cluster potential and are stripped to produce the abundant S0s we see in present day clusters. The evidence of radial gradients in diagnostic spectral features is particularly convincing support of this picture (Abraham et al 1996a). On the other hand, the small scatter seen in the S0 population at all epochs thus far studied is puzzling and, at least in the core regions, there appear to be some genuine ellipticals which have surprisingly strong $H\delta$ absorption lines indicating recent star formation (Barger et al 1996a).

A worry with all these studies thus far is the absence of a clear understanding of how the clusters were selected. Kauffmann (1996) argues that, by selecting the richest clusters at a given redshift, we are unlikely to be studying the precursors of present-day clusters. An X-ray flux-limited sample may not be much better given our limited physical understanding of the evolution of the X-ray luminosity (Castander et al 1995). Ultimately, one might contemplate undertaking a comprehensive survey using gravitational lensing to locate mass in a well-defined manner. At that stage of complexity, it is probably simpler to undertake very large field surveys if the primary goal is to understand the galaxy population.

## 3 Evolution of Field Galaxies

The surveys of Bergeron & Boissé (1991) and Steidel et al (1994) based on the identification of the galaxies responsible for Mg II absorption in QSO spectra indicate little change in the overall luminosity function (LF) of regular field galaxies to $z \simeq 0.7$. However, several details remain unclear with the interpreta-

tion of such samples in the context of galaxy evolution. These include the weak correlation between impact parameter and Mg II equivalent width (Churchill 1996) and the apparent absence of prominent absorption from gas-rich dwarf galaxies. Although viewing galaxies via their absorbing effects provides a valuable complement to the more traditional redshift surveys, it may be that complex selection biases operate in such samples.

On the other hand, it certainly is reassuring that the LFs of the absorbers can be reconciled with the results emerging from the deep redshift surveys. Impressive progress has been made in the past 2 years from the comprehensive surveys of the CFRS group (Lilly et al 1995), the LDSS/Autofib team (Colless et al 1990, Glazebrook et al 1995a, Ellis et al 1996b) and at the Keck (Cowie et al 1996). Collectively, the number of faint (>20 mag) redshifts is now over 1000 (Table 1) and each provides a complementary insight into the distant population.

The CFRS survey is $I$-selected and well-suited for sampling the evolving population of massive galaxies to $z \simeq 1$. In contrast, the LDSS/Autofib survey is $b_J$-selected and particularly tuned to address the nature and distribution of the faint blue population which lies around or fainter than $L^*$. The wide apparent magnitude range of this survey makes it ideally suited for exploring changes in the *shape* of the luminosity function with redshift. The unusually good spectral resolution also makes it appropriate to examine evolutionary trends as a function of spectral class (Heyl et al 1996). The Keck survey by Cowie et al is $K$-selected and thus at high redshift is least affected by uncertainties in $k$-corrections. Moreover, by using multicolour data, Cowie et al have extended their survey in order to construct $B$ and $I$ surveys to slightly deeper limits than has been possible on 4-m telescopes.

**Table 1.** Deep Redshift Surveys

| | Reference | $N_{gal}$ | Selection |
|---|---|---|---|
| CFRS | Lilly et al (1995) | 591 | $I$ <22 |
| LDSS | Ellis et al (1996b) | 1726 | 17< $b_J$ <24 |
| Keck | Cowie et al (1996) | 346 | $K$ <20 |
| | | 203 | $B$ <24.5 |
| | | 130 | $I$ <22.5 |

The empirical trends found by all 3 survey teams agree remarkably well in the sense that the evolutionary changes seen are strongest in the star-forming population which progressively occupy the fainter part of the LF at lower redshift. Given the different perspectives and survey strategies of the teams this is encouraging! Lilly et al (1996) characterise the global evolution in terms of the mean rest-frame luminosity density at various wavelengths and claim this corre-

sponds to an order of magnitude decrease in the volume-averaged star formation rate since a redshift $z \simeq 1$.

The difficulty lies in the physical interpretation of the declining star formation rate in terms of the various populations and, in particular, the question of whether number evolution is required. The traditional 'faint blue galaxy' problem has been sold as requiring an 'excess population' which fades or merges by $z \simeq 0$ (e.g. Ellis 1996). Is it possible to directly identify such an excess population from the redshift surveys?

The CFRS team claim that the LF evolves such that the most rapid change occurs for those galaxies with rest-frame colours bluer than a typical Sbc. They discuss various galaxy populations whose characteristic evolutionary timescale differ. Number density evolution is not invoked. Although a very deep and well-controlled survey (the median redshift is $z \simeq 0.6$), the *time* baseline is fairly modest since there are few galaxies below a redshift of 0.3.

The LDSS team place greater emphasis on the changing *shape* of the LF in the sense that the faint end slope steepens with increasing redshift. Such a behaviour is not unexpected, at least qualitatively, in hierarchical merging. By subdividing their large sample according to [O II] strength and spectral class (Heyl et al 1996), they conclude that the bulk of the evolution can be characterised by a strong luminosity and/or number density evolution of the late type population. Crucial to the need for number evolution is the assumed form for the local LF. A flat (Schechter $\alpha$=-1) local LF would imply fairly dramatic changes have taken place between $z \simeq 0.5$ and today, and thus it is reasonable to question the reliability of the local LF before accepting this conclusion (McGaugh 1994).

Glazebrook et al (1995a), Ellis et al (1996b) and Cowie et al (1996) have each placed constraints on the faint end slope of the local LF from the absence of low $z$ galaxies in their deep $B$-selected surveys and reject the hypothesis (Gronwall & Koo 1995) that the counts can be understood solely in terms of a local LF with a steep faint end slope. On the other hand, it is clearly worrying that the same authors admit a LF normalisation ($\phi^*$) markedly higher than traditional estimates (e.g. Loveday et al 1992). Part of the difficulty may be the degree to which brighter photographic photometry can be effectively tied to that of the faint surveys (Bertin & Dennefeld 1996) and this is closely tied to the important role that surface brightness plays in isophotal surveys (Ferguson & McGaugh 1994).

What evidence is there for short-term star formation activity such as might be expected if merging is an ingredient driving the evolution? Broadhurst et al (1988) first suggested that the faint blue star-forming sources had spectral characteristics indicating short-term bursts rather than a gradual decline in the star formation rate. More recently, Heyl et al (1996) have found a similar effect in the more extensive LDSS and Autofib survey (Figure 2). In the blue-selected samples, a high proportion of the spectra are unlike those of local spirals. For this class of object there is also a marked increase in the median [O II] 3727 Å equivalent width with redshift (Figure 3).

Assuming galaxy morphology is a marker with some degree of permanence,

**Fig. 2.** Coadded spectra for late-type spiral galaxies in the LDSS/Autofib survey (Heyl et al 1996). The bold curve is the coaddition of those with $z$ <0.2 while the light curve is for those with 0.2< $z$ <0.5. The higher redshift sample shows absorption lines whose increased strength is indicative of recent (≃1 Gyr) star formation.

**Fig. 3.** Evolution of the median [O II] equivalent width for late-type spirals in the LDSS/Autofib survey (Heyl et al 1996).

HST galaxy counts can provide valuable insight into the galaxies that are responsible for the LF changes discussed above. Glazebrook et al (1995b) and Abraham et al (1996b) provide type-dependent counts to $I$=25 from the Medium Deep Survey and the Hubble Deep Field and claim a remarkable overabundance of irregular galaxies compared to local samples. Many are certainly suggestive of merging, although firm quantitative proof is difficult to establish (Neuschaefer et al 1995). Although these counts probe much deeper than the current redshift survey limits, the basic conclusion is that the number of regular spheroidal and disk galaxies to $I$ ≃22-23 is fairly close to no evolution expectations, whereas the bulk of the excess population seems confined to the irregular sources.

But how reliable are the morphological assignments in these faint samples? Abraham et al (1996c) have addressed this question via the development of more

quantitative classification criteria based on assymmetry and light concentration and via simulations that take account, on a pixel-by-pixel basis, of differential $k$-corrections and surface brightness dimming. For z<1, where the bulk of the $I$ <22 galaxies lie, the biases are quite small and amount, for example, to confusion only between Sdm, Irregular or merging systems rather than gross misclassification such as movement from Sbc to Irr. As local irregulars and late type spirals should not be difficult to see if they are still actively producing stars, their abundance in the HST counts compared to a paucity in local data is an important result.

The HST and ground-based data thus both assign a high proportion of the evolution to a single class, namely late-type spirals and irregulars. The mean luminosity and perhaps number density of this class of sources is rapidly decreasing with time. This is not to say there is not room for some evolution in the intermediate spirals or ellipticals. The CFRS and LDSS teams have joined forces and will soon have over 300 galaxies for which HST images and spectra will be available to $I$=22 and $b_J$=24. Schade et al (1996) have already claimed quite significant evolution in the surface brightness of disk galaxies with redshift and this work is being extended to the larger CFRS+LDSS database. Additionally, the luminosity and redshift distribution of morphologically-distinct samples is being analysed in the context of the question of whether number evolution is required.

The most significant conclusion thus far from the redshift surveys is the global evolution of the population (Lilly et al 1996) rather than results based upon dissection into individual types whose physical significance remain unclear. Nonetheless, for a detailed understanding of the origin of disk galaxies and a resolution of the 'faint blue galaxy problem' it is clear this is the way to go although possibly very large joint HST and ground-based spectroscopic samples will need to be gathered.

## 4 Exploring $z$ >1

The Hubble Deep Field has provided an exciting first glimpse into the distant Universe. By extending the galaxy counts to a regime affected by ground-based confusion, it is now clear that the surface density of very faint sources exceeds that predicted on the basis of most reasonable local luminosity functions, suggesting either: (i) galaxies are not conserved, viz. in the HDF we are seeing sub-units destined to become larger systems, or (ii) we live in a world model where $\Lambda \neq 0$.

Although $\Lambda$-dominated models remain popular in theoretical circles, the observational constraints are getting tighter. If the excess counts were produced primarily by huge volumes, one would see similar effects in the $K$-band (Djorgovski et al 1995). Spatially-flat models with $\Lambda \neq 0$ would also produce accelerating universe which seem in conflict with the constraints emerging from the distant supernovae programmes (Perlmutter et al 1996, Leibundgut, this volume).

There is growing evidence that the bulk of the star formation that made the present day population occurred between $1< z <3$. Firstly, the steep rise in star

formation rate to redshift $z \simeq 1$ is a major pointer to a low redshift of mean star formation (Fall et al 1996). Secondly, a key result, suggested initially by Guhathakurta et al (1990), is the rarity of $R<25$ star-forming sources whose $U$ band flux indicates a strong Lyman limit consistent with $z>3$. The same result has been derived by Steidel and collaborators with the important advance that candidate Lyman limit sources beyond $z \simeq 2.3$-3 have now been spectroscopically verified using the Keck telescope both in the HDF (Giavalisco et al 1996) and elsewhere (Steidel et al 1996).

If the bulk of the star formation occurred at low redshift, could the high $z$ star-forming galaxies recently identified be the ancestors of the present day spheroidal galaxies? HST images of those HDF galaxies satisfying Abraham et al's (1996c) Lyman-limit criteria are shown in Figure 4 and are highly suggestive of hierarchical merging of sub-units in the manner predicted by Kauffmann (1996) and Baugh et al (1996). However, a crucial pointer in this regard would be an estimate of the mass of such distant systems, either from resolved spectroscopy or absorption line widths (c.f. Giavalisco, this volume).

It is important to recognise that the Lyman-limit method, although remarkably effective, provides only a limited view of the high redshift Universe, namely star-forming sources within a narrow redshift range. Our inability to immediately 'connect' this interesting population with low $z$ counterparts exemplifies the need to provide complete redshift coverage so the evolution of the various samples can be directly tracked.

How are we going to *systematically* explore the galaxy population beyond $z \simeq 1$ in a manner similar to that which has been so successful with the 4-m telescopes for $z<1$? If our hypothesis concerning the star formation history is correct, the redshift interval $1<z<2.5$ is particularly important yet, paradoxically, this is a range which will be the hardest to systematically explore with the first tranche of 8-m instruments. The basic difficulty is the absence, at optical wavelengths, of any of the familiar diagnostic features. Although one is encouraged by the detection of absorption lines in the Keck spectra to faint limits, I am confident those same sources would be far easier to study at infrared wavelengths where their emission line spectra would be quite prominent.

At this conference we have witnessed three promising techniques. Firstly, the weak lensing signals seen in a variety of clusters provide valuable information on the mean statistical distance to an objective sample of very faint images viewed through the cluster lens (Fort, this volume). In certain clusters, the mass models are sufficiently tightly constrained (Kneib et al 1996) that the modelling can be used to estimate distances to very faint sources viewed through the lens. The process can be iteratively improved via arclet redshift measurements to make quite precise statements about extremely faint galaxies. A dramatic verification of this 'inversion' technique is the $z$=2.515 arc in Abell 2218 (Ebbels et al 1996, Figure 5) originally predicted to be a $R_{true}$=24.1 galaxy at $z \simeq 2.8 \pm 0.3$. This is just the beginning of several approaches which, through calibration spectroscopy and HST imagery, will provide mean distances to a variety of galaxy populations at very faint limits. As these methods are geometric, they avoid many of the

**Fig. 4.** Hubble Deep Field images of those galaxies selected by Abraham et al (1996b) to have Lyman limit drop outs suggesting they lie at redshifts $z>2.3$. A significant fraction have since been spectroscopically confirmed (Giavalisco et al 1996).

biases inherent in traditional surveys.

Secondly, a high priority must be the effective use of the panoramic infrared spectrographs on 8-10m telescopes to sample the wavelength range where red-shifted [O II] and $H\alpha$ lie. The troublesome OH background necessitates high dispersion which is costly in detector pixels. The VIRMOS project (LeFevre, this volume) is an imaginative and ambitious solution to this problem. The third technique is the highly complementary CADIS narrow band imaging programme (Meisenheimer, this volume). On the relative merits of these two techniques, I

**Fig. 5.** Spectrum of a faint arc (#384) in the rich cluster Abell 2218 obtained with LDSS-2 on the WHT (Ebbels et al 1996). The spectroscopic redshift of 2.515 agrees closely with that inferred from the lensing inversion method developed by Kneib et al (1996) and illustrates the potential of determining the mean redshift of a very faint population of galaxies viewed through a lensing cluster.

believe it will be important to execute some scouting missions to determine the likely distribution of emission line strengths before finalising the design parameters of a major commitment like VIRMOS. One would hardly contemplate embarking on 2dF or the Sloan Digital Sky Survey without having gathered a representative set of optical galaxy spectra.

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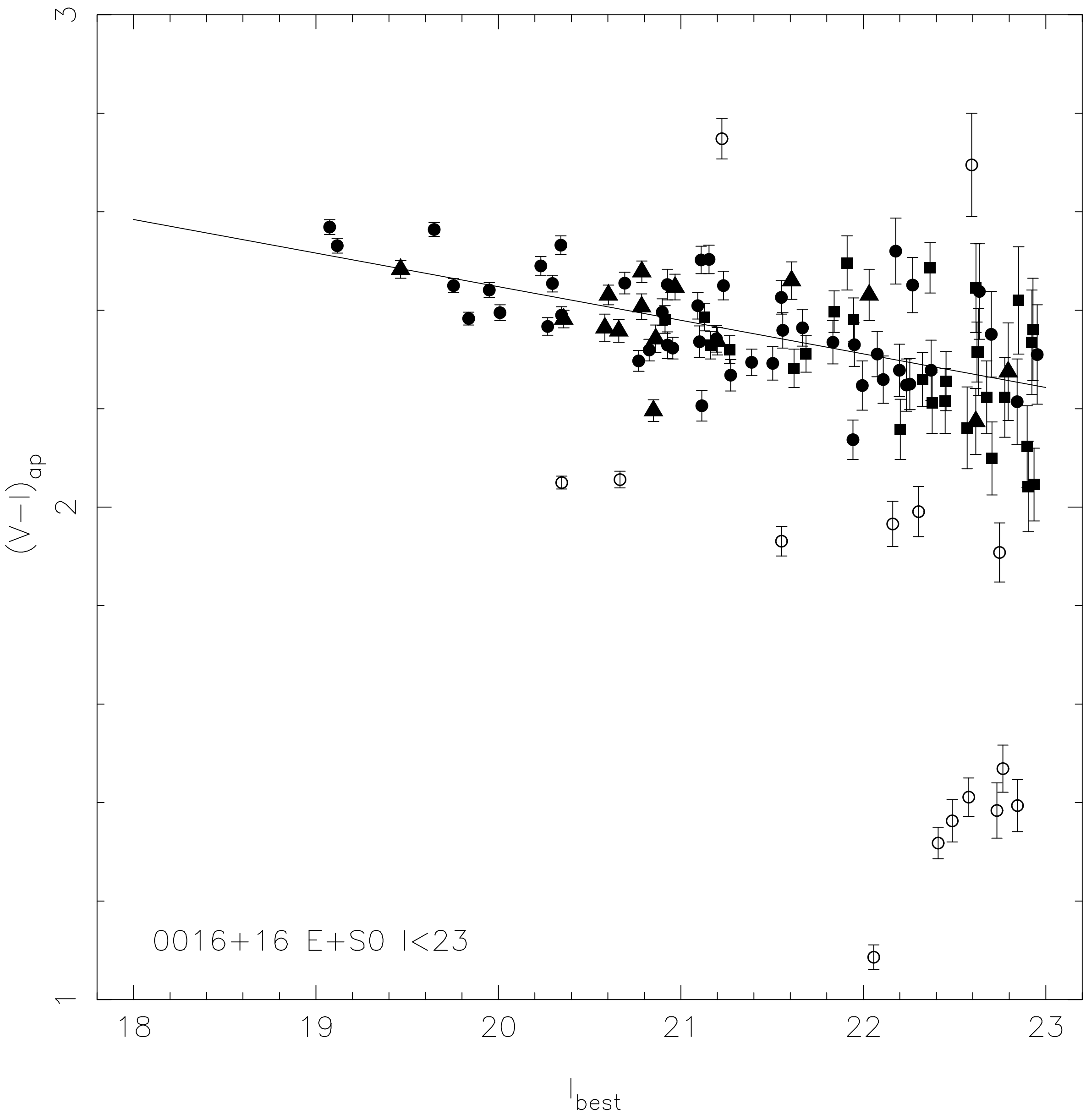

3
2
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18
19
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21
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23
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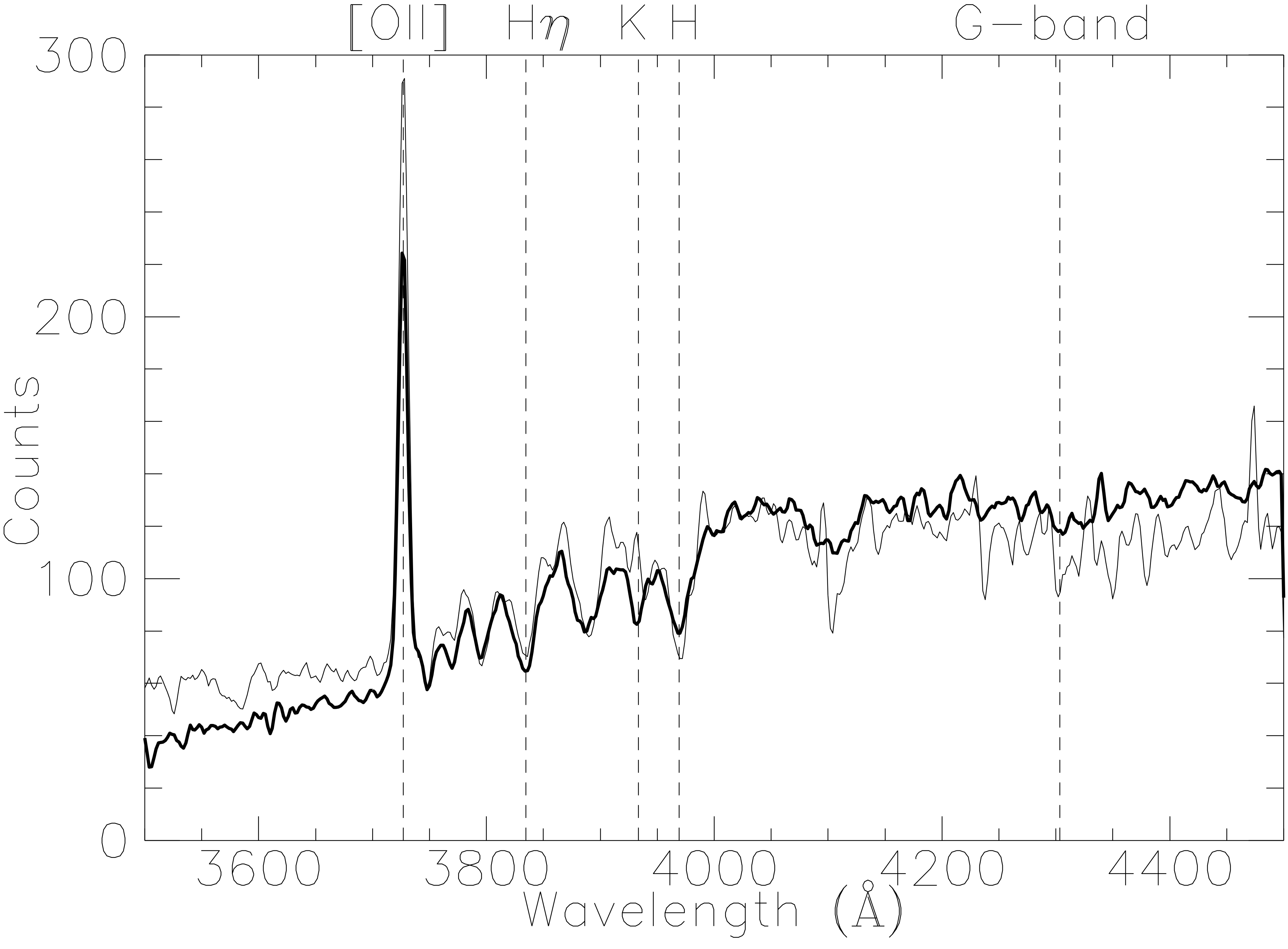
[OII]
Hη
K
H
G—band
Counts
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200
100
0
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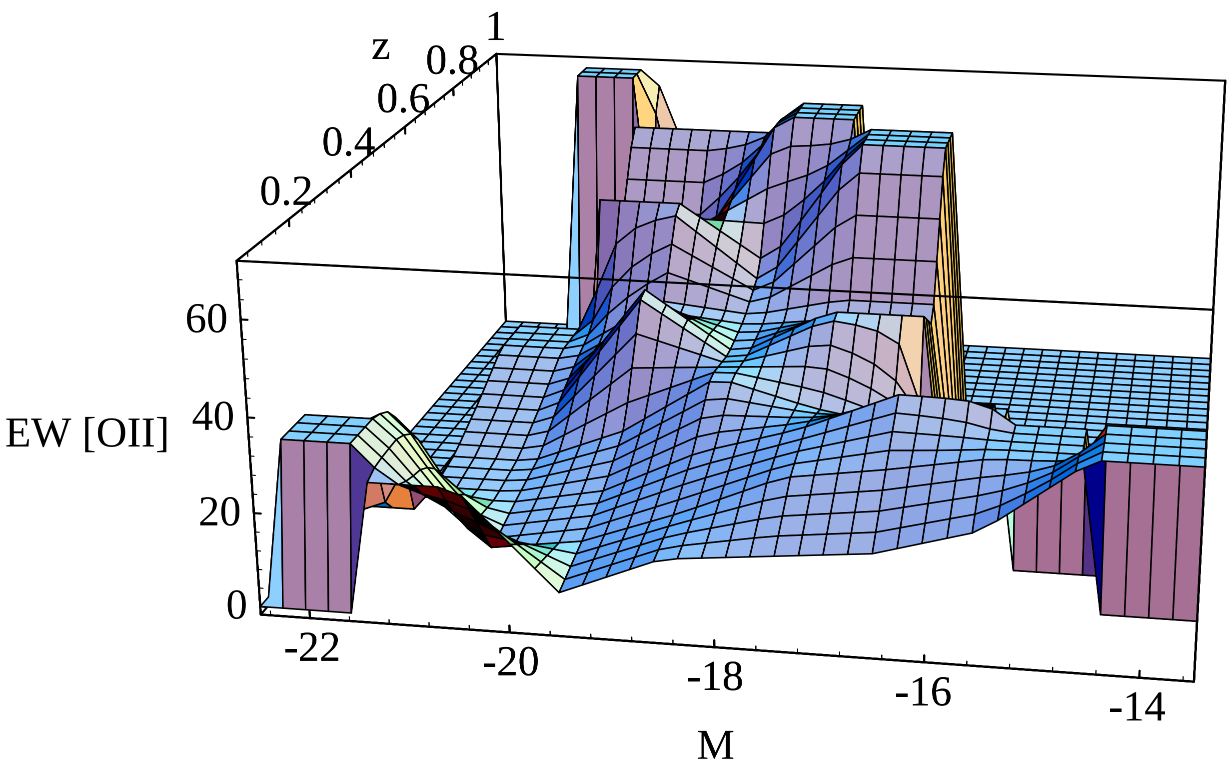
4400
Wavelength (Å)



z
1
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0.4
0.2
60
40
20
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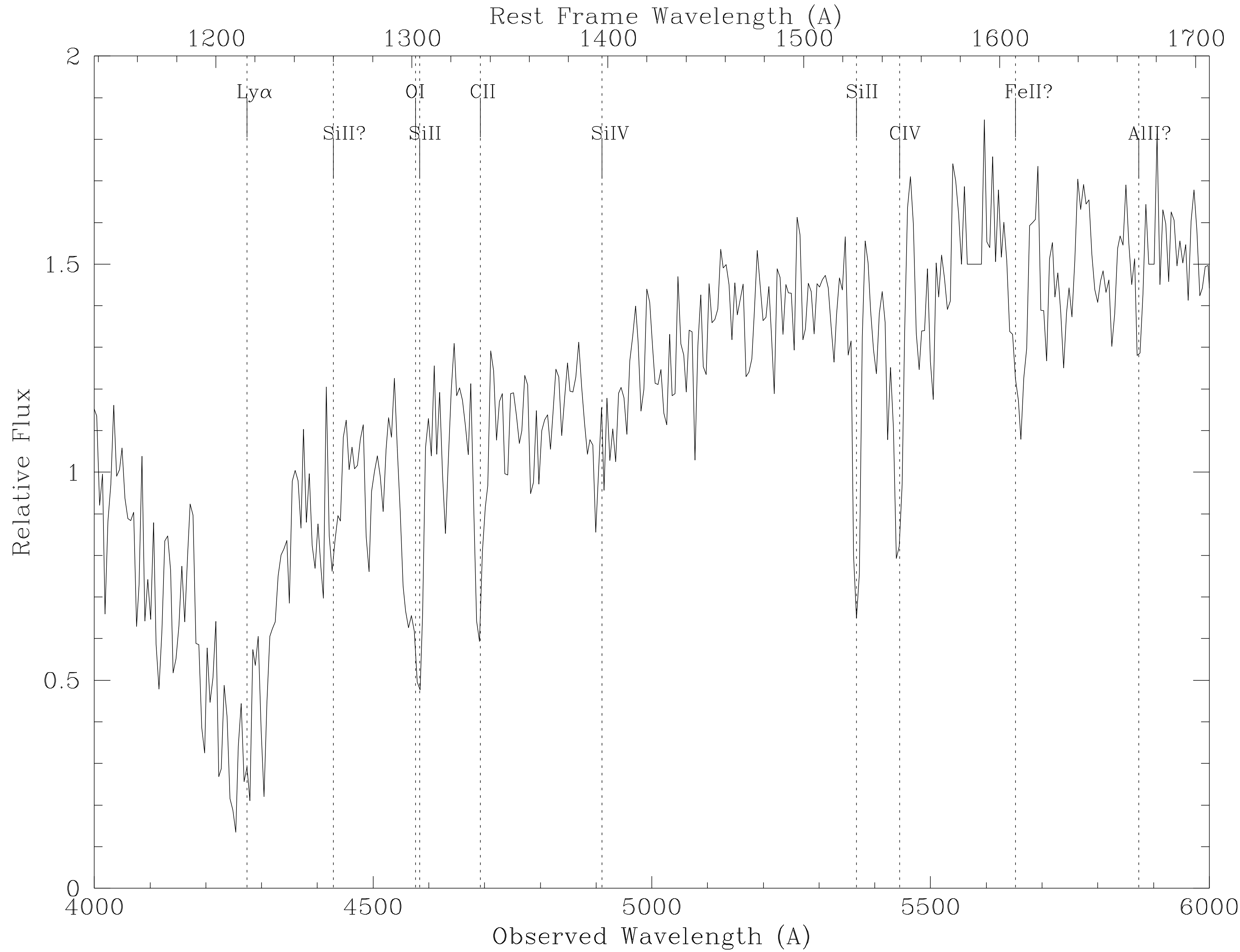
EW [OII]
-22
-20
-18
-16
-14
M


Rest Frame Wavelength (A)
1200
1300
1400
1500
1600
1700
Lyα
SiII?
OI
SiII
CII
SiIV
SiII
CIV
FeII?
AlII?
Relative Flux
0
0.5
1
1.5
2
4000
4500
5000
5500
6000
Observed Wavelength (A)